Paleocene palynomorph assemblages from the Nacimiento Formation, San Juan Basin, New Mexico, and their biostratigraphic significance

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Abstract

The Nacimiento Formation bears vertebrate faunas that are types for the Puercan and Torrejonian North American Land Mammal Ages (NALMAs). A biostratigraphy based on therian mammal distribution in the Nacimiento Formation can be tied to magnetostratigraphy. This is correlated to a geomagnetic polarity time scale, forming an important geochronologic and biochronologic framework for regional correlation. Two palynomorph assemblages recovered from the Paleocene Nacimiento Formation in Kimbeto Arroyo, San Juan Basin, New Mexico, can be correlated to a Paleocene palynostratigraphic zonation of western North America, providing an independent and significant biochronologic correlation. The first sample (SJB03-17) is from a carbonaceous mudstone ~1 m (~3 ft) below strata of the Puercan (Pu2) NALMAs and in a zone of normal magnetic polarity correlated with polarity subchron C29n. It yielded an assemblage including *Arecipites* sp., *Corollina* sp., *Laevigatosporites* sp., *Momipites tenuipolus*, *Nyssapollenites* spp., *Pityosporites* sp., *Tricolpites anguloluminosus*, *Tricolpites* spp., and *Ulmipollenites krempii*. The second sample (SJB03-19) is from a carbonaceous mudstone approximately 2 m (6.5 ft) above strata that yield a basal Torrejonian (To1) NALMA vertebrate fauna and within a succeeding zone of normal magnetic polarity correlated with polarity subchron C28n. It yielded an assemblage including *Cicatricosisporites* sp., *Corollina* sp. (common), *Laevigatosporites* sp., *Momipites triorbicularis* (common), *Pityosporites* spp., *Tricolpites anguloluminosus*, *Ulmipollenites krempii*, and *Zlivisporis novomexicanum*.

SJB03-17 contains *Momipites tenuipolus*, a taxon that is widespread in the lower Paleocene in the Western Interior. Its occurrence in this sample in the lower Nacimiento Formation is consistent with its known stratigraphic range. SJB03-19 yields *Momipites triorbicularis*, a taxon that indicates a correlation with Paleocene palynostratigraphic Zone P3 (the *Momipites actinus–Aquilapollenites spinulosus* Interval Biozone), a zone identified throughout the lower Paleocene of the Western Interior. The identification of Zone P3 in the Nacimiento Formation closely associated with a To1 vertebrate assemblage firmly establishes a correlation between a Paleocene palynostratigraphic and vertebrate biostratigraphic zonation. This is consistent with most recent age correlations proposed for the Nacimiento Formation and provides an important biochronologic correlation for the Western Interior.

Introduction

The Paleocene was a time of dramatic restructuring of terrestrial ecosystems and rapid diversification of many groups of animals and plants following the Cretaceous–Tertiary (K–T) mass extinction. The San Juan Basin (Fig. 1), a foreland basin formed during the Laramide orogeny, contains a long and relatively continuous depositional record spanning the K–T boundary and the early Paleocene (Fig. 2). The record of mammalian succession of the Nacimiento Formation is particularly important as it is the longest and most complete for the early Paleocene of North America. This record has been crucial for constructing a biochronologic framework for the early Paleocene based on the succession of mammalian faunas, the North American Land Mammal Ages (NALMAs). The continuing goal is to refine NALMAs and tie them to other biological and geological time markers (Woodburne 2006). A biochronology of the early Paleocene of western North America, tied to the geomagnetic polarity time scale (GPTS), and in some places, constrained by radiometric ages obtained from volcanic ashes, is well established (Lofgren et al. 2004). The type faunas for the two NALMAs ushering in the age of mammals, the Puercan and Torrejonian, are from the Nacimiento Formation.

In an effort to refine early Paleocene biostratigraphy and biochronology, Williamson (1996) proposed a therian mammal biostratigraphy based on lithostratigraphic correlation of fossil localities in the Nacimiento Formation. This was tied to an existing magnetostratigraphy (Lindsay et al. 1981) that provided tie points to the GPTS. The resulting biochronology provided the chief basis for the latest revision
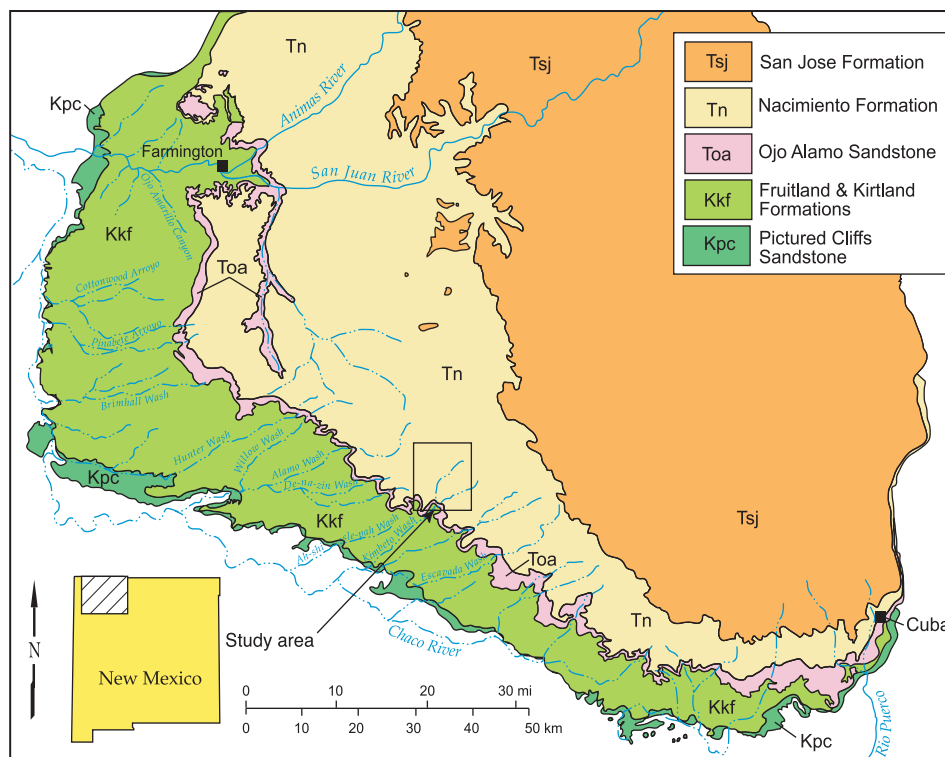

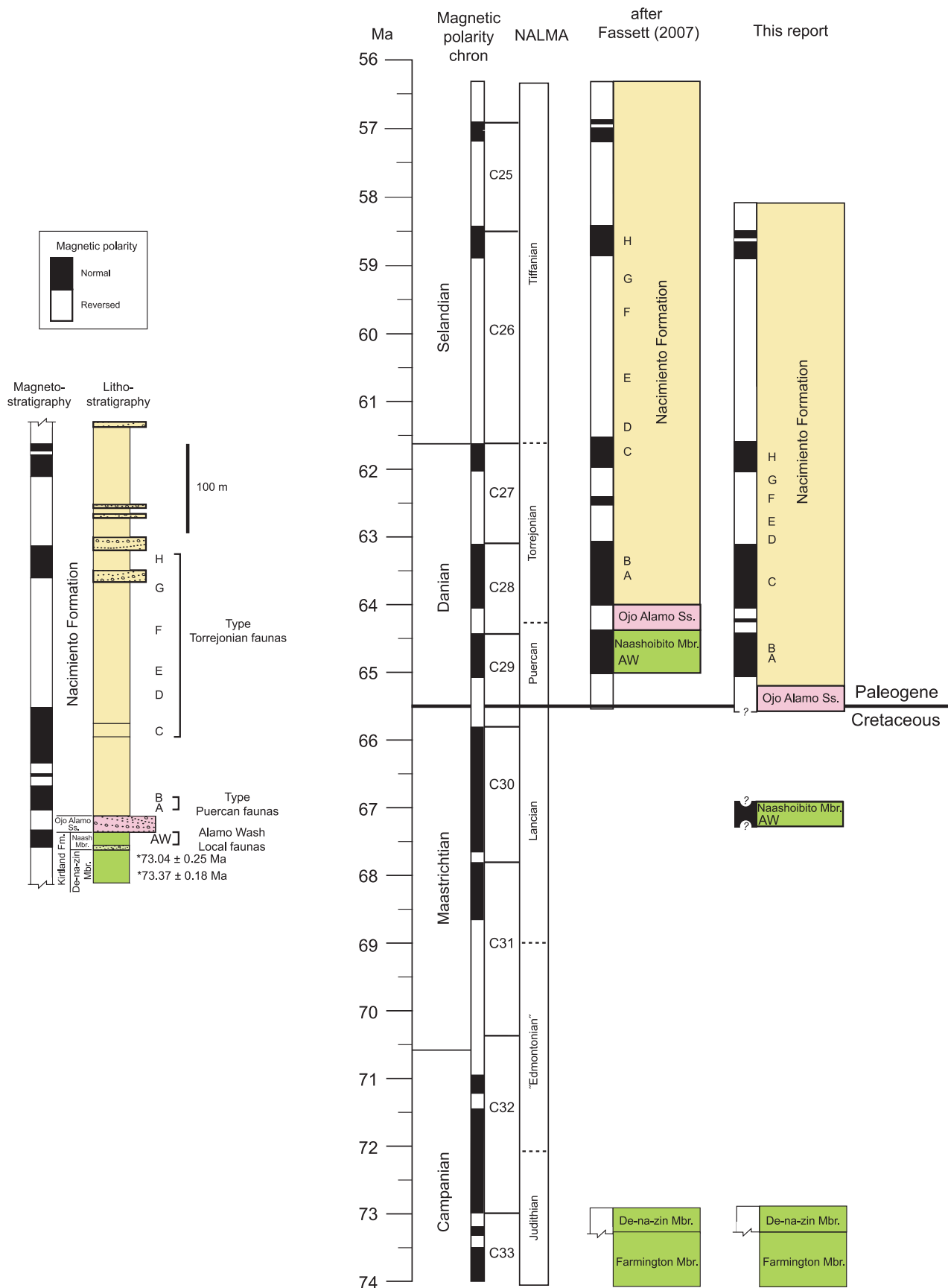FIGURE 1—Geologic map of the San Juan Basin, northwestern New Mexico (after Williamson 1996).

FIGURE 2—Stratigraphy of the San Juan Basin spanning the Cretaceous–Tertiary boundary and early Paleocene with two differing hypotheses regarding the age correlation of these strata. Radiometric ages from volcanic ashes in the De-na-zin Member are shown as published by Fassett and Steiner (1997) and are not corrected using updated decay constants after Renne et al. (1998) and Knight et al. (2003). The composite stratigraphic section and magnetostratigraphy of Upper Cretaceous and Paleocene deposits are after Lindsay et al. (1981). Fossil zones A–H are from Williamson (1996). The time scale is from Gradstein et al. (2004).

of the Puercan and Torrejonian NALMAs (Lofgren et al. 2004).

Recently, Fassett (2001, 2007) suggested that age correlation of the Nacimiento Formation based on mammals is in error. Fassett and others, in a number of papers (e.g., Fassett et al. 1987; Fassett and Lucas 2000; Fassett et al. 2000, 2002; Fassett 2001, 2007), argued that sediments of the Naashoibito Member, Kirtland Formation (sensu Baltz et al. 1966), yielding non-avian dinosaurs are Paleocene in age. The Naashoibito Member contains a zone of normal polarity. This was later attributed to overprinting (Butler and Lindsay 1985). However, Fassett (2001, 2007) argued that this zone of normal polarity reflects remanent magnetization and is correlated with subchron 29n. If correct, correlation of this zone to subchron 29n would necessitate a revision of the correlation of the magnetostratigraphy of the overlying Nacimiento Formation with the GPTS resulting in a significantly different age assessment for the Nacimiento Formation and its vertebrate faunas (Fig. 2). Such a conclusion would therefore not only have important implications to extinction across the K–T boundary, but also to the efficacy of early Paleocene mammal biostratigraphy, biochronology, and evolutionary studies (e.g., Alroy 1999). In order to test this hypothesis, an independent age assessment for key horizons of the Nacimiento Formation is required.

Against this backdrop, two new palynomorph assemblages from the Nacimiento Formation in Kimbeto Wash are reported. The objectives of this paper are to review the biostratigraphy and biochronology of the Nacimiento Formation based on fossil mammals, review the magnetostratigraphy and its correlation to the GPTS, and discuss the biostratigraphic and biochronologic significance of the new palynomorph assemblages reported here.

Abbreviations

AMNH, American Museum of Natural History, New York; KU, Museum of Natural History, University of Kansas, Lawrence; NMMNH, New Mexico Museum of Natural History and Science, Albuquerque; UALP, University of Arizona Laboratory of Paleontology, Tucson; UCM, University of Colorado Museum, Boulder.

Nacimiento Formation mammal biostratigraphy and biochronology

The Nacimiento Formation of the San Juan Basin contains many fossil vertebrate localities. These have been collected for more than 100 yrs and are well documented (Williamson 1996). Vertebrate fossils of the Nacimiento Formation are commonly restricted to fossiliferous zones bounded by "sterile" or "barren" intervals. Williamson (1996) correlated these fossiliferous zones of the Nacimiento Formation using

lithostratigraphy and compiled them into a series of eight successive fossiliferous zones, labeled A–H in a composite section (Fig. 2). These zones can be considered as "paleontologically distinct lithozones" as defined by Walsh (2000). The lowest two zones, A and B, yield the type Puercan NALMA faunas. The succeeding six fossil zones yield the type Torrejonian NALMA faunas.

Williamson (1996) erected eight biostratigraphic zones based on interval zones of fossil mammals as distributed among the eight fossiliferous zones. These zones can be tied directly to the Nacimiento Formation lithostratigraphy and magnetostratigraphy, facilitating correlation between biological and geochronological events. Notably, the resulting biochronology differs conceptually from that of the NALMAs (see Woodburne 1987, 2004).

In the study area, encompassing the east and west flanks of Kimbeto Wash, are several diverse fossil localities within three distinct fossil zones (Figs. 3, 4). The lowest of these is from close to the base of the Nacimiento Formation and is restricted to a relatively narrow fossiliferous band bounded above and below by intervals barren of vertebrate fossils (Williamson 1996). This fossiliferous zone is referred to as the "*Ectoconus* zone" (sensu Sinclair and Granger 1914) or "*Hemithlaeus* zone" (sensu Van Valen 1978). The fauna recovered from this horizon is regarded as the "type fauna" for the middle Puercan (Pu2) sensu Lofgren et al. (2004). The late Puercan (Pu3) is based on the fauna from the

"*Taeniolabis* zone" (Archibald et al. 1987; Lofgren et al. 2004). However, strata yielding the Pu3 fauna are not present or are not fossiliferous in Kimbeto Wash (Williamson 1996). The fossil localities from the lowest fossil zone of the west flank of Kimbeto Wash locale were collectively referred to as locality 11 in Williamson (1996, appendix 3; Figs. 3, 4; precise locality information is on file at the NMMNH). This locale includes the site AMNH locality 5 as well as Standhardt's (1980) Black Toe site, a microvertebrate fossil locality. This fossil zone can be
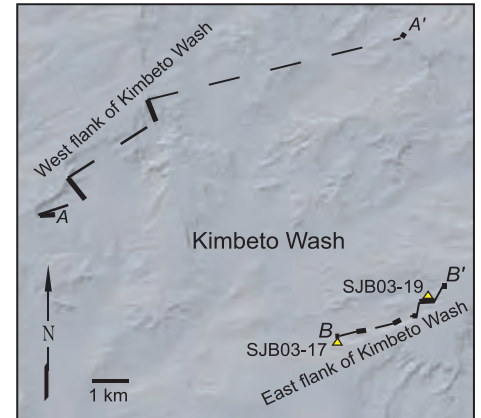

FIGURE 3—Digital elevation model of Kimbeto Wash (portions of the Kimbeto and Blanco Trading Post USGS 7.5-min topographic maps) showing location of measured sections on the west (*A–A'*) and east (*B–B'*) flanks of Kimbeto Wash. Locations for samples for palynomorphs SJB03-17 and SJB03-19 from the east flank of Kimbeto Wash are marked.
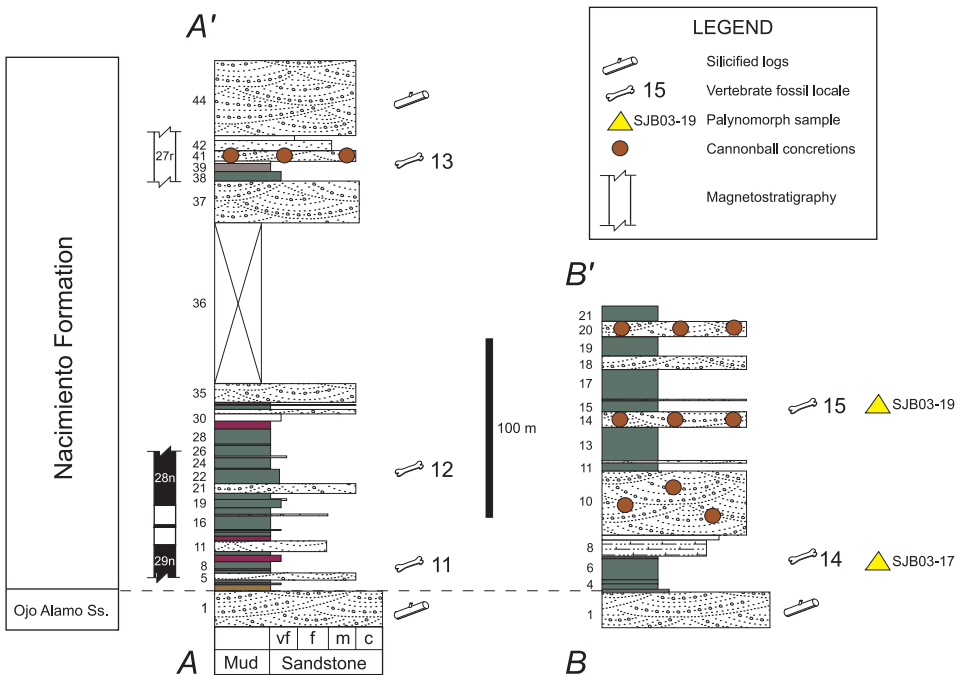

FIGURE 4—Measured sections *A–A'*, west flank of Kimbeto Wash, and *B–B'*, east flank of Kimbeto Wash (modified from Williamson 1996, appendix 1, measured sections K and L, respectively). The magnetostratigraphy of Lindsay et al. (1978) is superimposed on the measured section from the west flank of Kimbeto Wash. Stratigraphic positions of vertebrate fossil locales from the west flank and east flank of Kimbeto Wash are also noted (modified from Williamson 1996, see text for details).

FIGURE 5—NMMNH P-19217, A right partial dentary of *Periptychus carinidens* with p1–m3 in labial (**A**), lingual (**B**), and occlusal (**C**) views.

correlated lithostratigraphically to the same fossil zone exposed on the east flank of Kimbeto Wash (locale 14, Williamson 1996, appendix 3; Figs. 3, 4); both are equivalent to the Black Stripe locality of Archibald et al. (1987) and AMNH locality 6. The lowest fossil zone of the Nacimiento Formation is known as "fossil zone A" (Williamson 1996, figure 18).

The next higher zone that yields fossil vertebrates is located at least 50 m (164 ft) above fossil zone A in Kimbeto Wash. This horizon, "fossil zone C," is generally sparsely fossiliferous, and fossils from this horizon are commonly heavily concreted. However, several localities within this zone from the west flank of Kimbeto Wash have yielded diagnostic mammal fossils including *Periptychus carinidens*. A partial dentary from this locale (NMMNH P-19217) is referred to *Periptychus carinidens* (Fig. 5).

In addition, a vertebrate microfossil site (NMMNH L-692 = UALP 77113) has produced a relatively large faunal assemblage consisting mostly of isolated teeth. This fauna was documented by Tomida (1980)

and expanded by Williamson (1996) and Williamson and Lucas (1993). It contains several mammals that indicate a Torrejonian age, including *Periptychus carinidens*, the taxon that defines the base of the Torrejonian (To1) NALMA (Lofgren et al. 2004) as well as the plesiadapiform genera *Palaechthon* and *Paromomys*, which first appear in the early Torrejonian (To1; Lofgren et al. 2004). These localities are collectively referred to as fossil locale 12 in Williamson (1996, fig. 9, appendix 3; Fig. 4). This fossil horizon can be correlated lithostratigraphically with strata exposed on the east flank of Kimbeto Wash that also yields fossil vertebrates. These correlative localities are collectively considered fossil locale 15 in Williamson (1996, fig. 9, appendix 3; Fig. 4).

A third fossiliferous zone, "fossil zone G" is found near the head of Kimbeto Wash and encompasses many localities including the "Little Pocket" (KU 9) locality.

Nacimiento Formation magnetostratigraphy

The magnetostratigraphy of the west flank of Kimbeto Arroyo was first documented by Lindsay et al. (1978, 1981). Tomida (1980) showed the relative positions of vertebrate fossil localities of the west flank of Kimbeto Arroyo relative to a magnetostratigraphic section. Williamson (1996) and Williamson and Lucas (1993) provided more detailed lithostratigraphic sections of the Nacimiento Formation exposed on the west and east flanks of Kimbeto Arroyo and also correlated these to the magnetostratigraphy of Lindsay et al. (1978, 1981) and UALP fossil localities.

There remains disagreement as to the correlation of Nacimiento Formation magnetostratigraphy to the geomagnetic polarity time scale (GPTS). Lindsay et al. (1978, 1980) and Tomida (1980) assumed that there were no significant disconformities within their paleomagnetic sequence, and, as a consequence, they correlated the lowest normal polarity zone with subchron

28n. This correlation was met with criticism (Lucas and Schoch 1982). Butler and Lindsay (1985) later correlated the lowest normal polarity zone with subchron 29n and attributed the normal polarity zone found in the Naashoibito Member to overprinting. We suggest that a significant disconformity is present between the base of the Ojo Alamo Sandstone (sensu Baltz et al. 1966) and the underlying Naashoibito Member of the Kirtland Formation as well as at the base of the Naashoibito Member (Williamson and Weil 2003; Fig. 2). We propose that a normal polarity signature for the Naashoibito Member, if accurately reflecting a true geomagnetic polarity, correlates with either subchron 30n or subchron 31n. Subchron 30n is estimated to occur between 65.86 Ma and 67.69 Ma, and subchron 31n is estimated to occur between 67.81 Ma and 68.73 Ma by Gradstein et al. (2004). Fassett (2001, 2007) disagreed with this correlation and argued that the normal polarity zone within the Naashoibito Member correlates with subchron 29n. This would necessitate a significantly different correlation of Nacimiento Formation magnetostratigraphy with the GPTS (Fig. 2) and a radically different age assignment for its vertebrate and palynomorph fossil assemblages.

The magnetostratigraphy for the lower Nacimiento Formation from the west flank of Kimbeto Wash (Fig. 4) indicates a normal polarity zone near the base of the section. This lowest normal polarity zone contains the type Puercan faunas of Kimbeto Wash. The next succeeding normal polarity zone contains the basal Torrejonian faunas of Kimbeto Wash. The intervening reversed polarity zone contains a "barren interval." The magnetostratigraphic section shows a narrow normal polarity zone within this reversed interval (Fig. 4).

Nacimiento Formation palynostratigraphy

Fossil pollen and spores are useful for Paleocene biostratigraphic correlation. A palynostratigraphic zonation of Paleocene strata of western North America subdivides the Paleocene into six zones (Nichols 2003). Three of these zones, P1–P3, span the early Paleocene and have proven useful for correlation in the northern Rocky Mountain region (Nichols 2003) and the Denver Basin (Nichols and Fleming 2002).

In 2003 two localities from the Nacimiento Formation of Kimbeto Wash were sampled and yielded palynomorphs. The first sample, SJB03-17, was obtained from a carbonaceous mudstone from 1 m (3 ft) below the base of unit 7 (Williamson 1996, appendix 1, section L; Fig. 4). Sample SJB03-17 yielded a moderately diverse assemblage including the species listed in Table 1. Selected palynomorphs from SJB03-17 and/or SJB03-19 are shown in Figure 6. *Momipites tenuipolus* (Fig. 6C) is widespread in the lower Paleocene in the Western Interior,
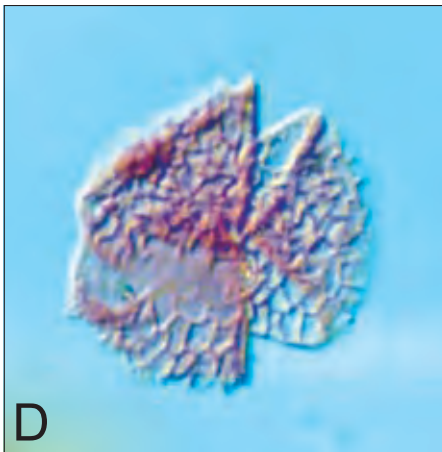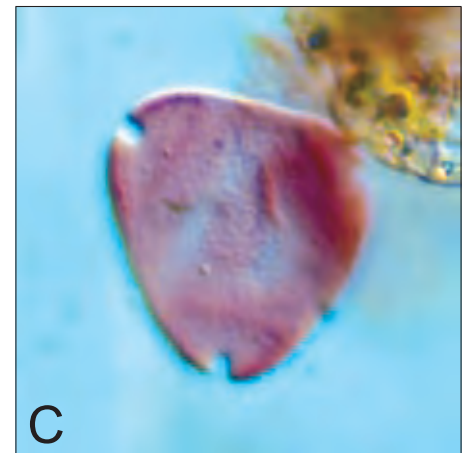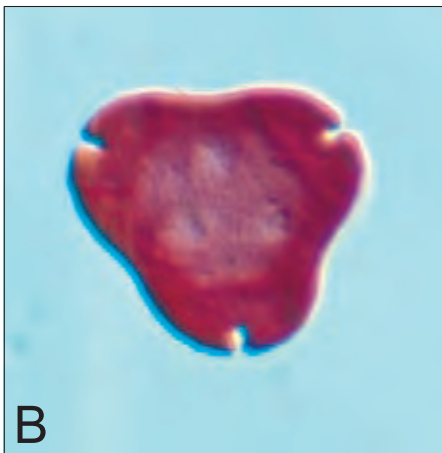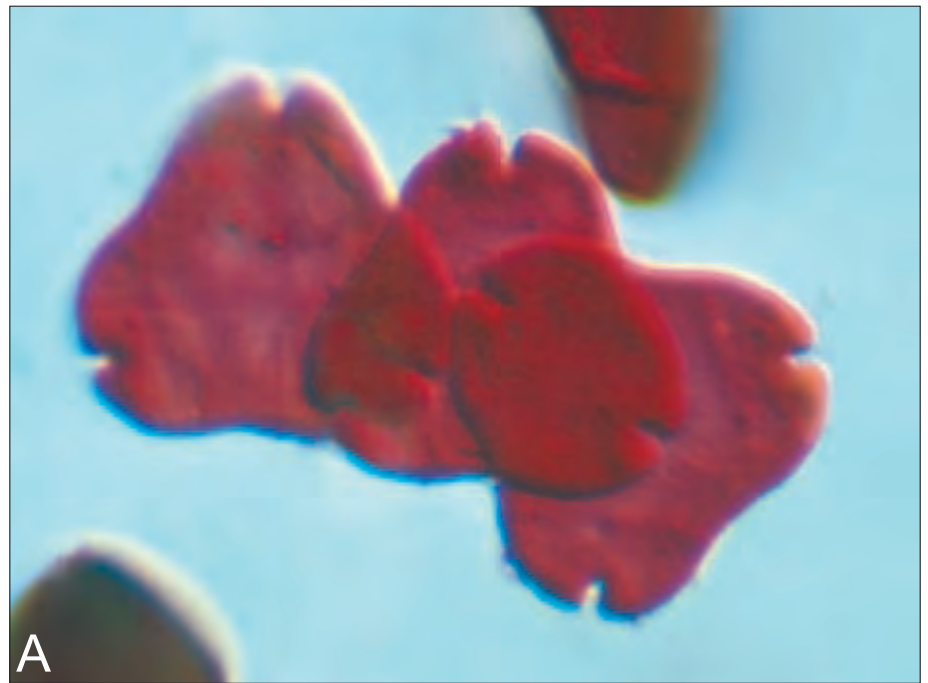

FIGURE 6—Selected diagnostic palynomorphs recovered from samples SJB03-17 and SJB03-19. **A, B**, *Momipites triorbicularis*; **C**, *M. tenuipolus*; **D**, *Tricolpites anguloluminosus*; and **E**, *Arecipites reticulatus*. Specimens are 20 µm in diameter.

spanning from P1 to P3, and its occurrence in a Puercan sample in the San Juan Basin is consistent with its known stratigraphic range (see Nichols 2003).

The second sample, SJB03-19, is from a carbonaceous mudstone 4 m (13 ft) above the base of unit 15 (Williamson 1996, appendix 1, section L; Fig. 4). Sample SJB03-19
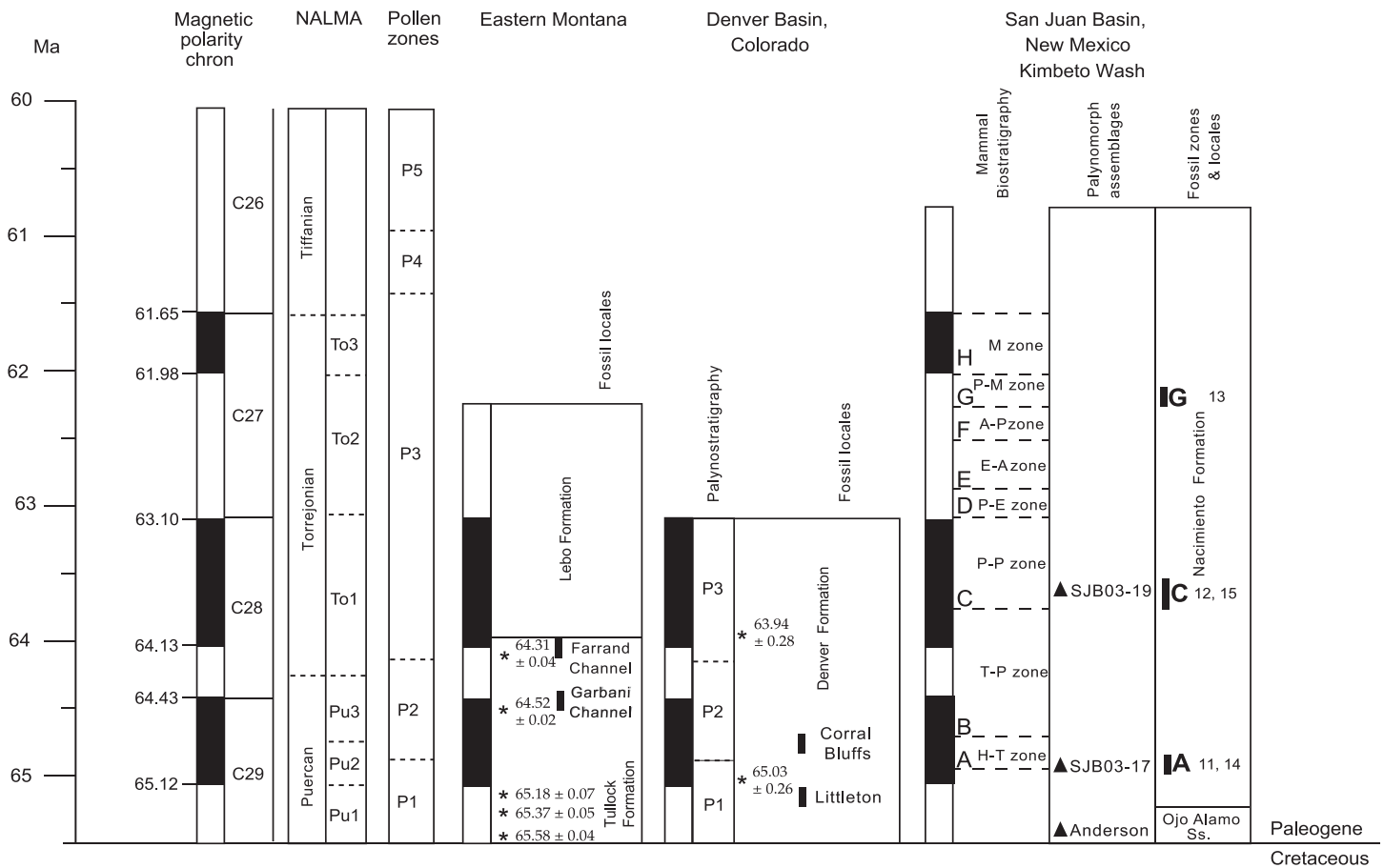
FIGURE 7—Correlation of the lower Paleocene strata of eastern Montana, Denver Basin, Colorado, and the San Juan Basin, northwestern North America with the geologic time scale of Gradstein et al. (2004). North American Land Mammal Age (NALMA) boundaries and subage boundaries are after Lofgren et al. (2004). Palynochronologic boundaries are after Nichols and Fleming (2002). Pollen zonation of the Denver Formation is after Nichols and Fleming (2002). The palynomorph assemblage labeled "Anderson" refers to the palynomorph assemblages from the Ojo Alamo Sandstone described by Anderson (1960). Numbered fossil vertebrate locales in the San Juan Basin are from Williamson (1996, fig. 9, appendix 3).

yielded a moderately diverse pollen assemblage listed in Table 1. *Momipites triorbicularis* (Fig. 6A, B) is present in Paleocene palynostratigraphic Zone P3 (the *Momipites actinus–Aquilapollenites spinulosus* Interval Biozone) throughout the Western Interior (Nichols 2003).

The resulting correlation of palynomorph assemblages of the Nacimiento Formation

with the Paleocene palynostratigraphic zonation is similar to that documented in the Denver Basin where palynomorph assemblages are tied to Puercan vertebrate fossil localities, magnetostratigraphy, and constrained by radiometric ages from volcanic ashes (Fig. 7). In the Denver Basin, palynomorph assemblages indicative of palynostratigraphic Zone P3 are also found in a normal polarity zone correlated with subchron C28n in both the Castle Pines core and the Kiowa core (Nichols and Fleming 2002; Hicks et al. 2003). At the Bijou Basin locality in the eastern Denver Basin, a volcanic ash, The Haas Tuff (Johnson and Ellis 2002; Obradovich 2002) occurs within a sequence of palynomorph samples indicative of Zone P3 (Nichols and Fleming 2002). It is dated at 64.1 ± 0.21

Ma, corroborating this magnetochronologic correlation.

The Nacimiento Formation palynomorph assemblage (SJB03-19) is indicative of palynostratigraphic Zone P3 and occurs in a normal polarity zone correlated with subchron C28n. This is consistent with the correlation of Paleocene palynostratigraphic Zone P3 in the Denver Basin. In addition, the SJB03-19 palynomorph assemblage is closely associated with vertebrate fossil locales (Fig. 4, locale 15) that yield earliest Torrejonian-age mammals (Williamson 1996). This is the first time that palynostratigraphic zones of the Western Interior have been tied directly to an early Torrejonian-age vertebrate fauna. This also provides an independent biostratigraphic age correlation for basal Nacimiento Formation strata. However, the P3 pollen zone extends through magnetochron 27 and into subchron 26r (Dunn, pers. comm. 2007). Therefore, the presence of P3 palynomorphs within a normal polarity zone does not necessarily preclude correlation with subchron 27n.

TABLE 1—Palynomorph assemblages recovered from the Nacimiento Formation.

	SJB03-17	SJB03-19
Arecipites reticulatus (Van der Hammen 1954)	*	
Nyssapollenites spp.	*	
Tricolpites spp.	*	
Cicatricosisporites sp.		*
Momipites tenuipolus Anderson 1960	*	
Tricolpites anguloluminosus Anderson 1960	*	*
Laevigatosporites sp.	*	*
Pityosporites spp.	*	*
Ulmipollenites krempii (Anderson 1960)	*	*
Corollina sp.	*	* (common)
Momipites triorbicularis Leffingwell 1971		* (common)
Zlivisporis novomexicanum (Anderson 1960)		*

Early Paleocene biochronology and magnetochronology of western North America

Mammal biochronology of the Rocky Mountain region provides an independent age correlation for the Nacimiento Formation. Several Puercan faunas of western North America are associated with a magnetostratigraphy that is constrained by radiometric ages (Fig. 7). These indicate that late Puercan vertebrate faunas (Pu2–Pu3, sensu Lofgren et al. 2004) occur in the normal polarity zone correlated with subchron 29n (Fig. 4, locales 11, 14) or in the lower part of subchron 28r. For example, the Garbani Channel vertebrate locality of the Tullock Formation of eastern Montana is associated with magnetostratigraphic data and constrained stratigraphically by volcanic ashes that have been radiometrically dated (Fig. 7; Swisher et al. 1993). The Garbani Channel fauna occurs in a channel complex and is probably a mixture of both Pu2 and Pu3 subages (Clemens 2002). However, the entire channel complex is contained within a normal polarity zone and bracketed by radiometric ages as between 65.18 ± 0.07 Ma and 64.52 ± 0.02 Ma (Wilson 2004; using the recalibration of Renne et al. 1998 and Knight et al. 2003), thus indicating a correlation with subchron 29n (Gradstein et al. 2004). The Garbani Channel fauna remains largely unpublished, but it contains the multituberculate *Taeniolabis* and the "triisodontine" *Eoconodon* cf. *E. gaudrianus* (Simmons 1987; Clemens and Williamson 2005) that establish a middle–late Puercan age (Pu2–Pu3; Lofgren et al. 2004). This indicates that middle and late Puercan faunas of the San Juan Basin also are contained within subchron 29n.

Early Torrejonian localities (To1 sensu Lofgren et al. 2004) of western North America are few and not well documented. The onset of Torrejonian time is defined as the first appearance of the periptychid "condylarth" *Periptychus carinidens* (Lofgren et al. 2004). The Nacimiento Formation and the North Horn Formation of Dragon Canyon, central Utah, contain the only certain To1 vertebrate faunas (Lofgren et al. 2004). The Dragon Canyon local fauna of the North Horn Formation, Dragon Canyon, yields a vertebrate fauna that was designated the type of the Dragonian NALMA (Wood et al. 1941). However, the "Dragonian" has since been incorporated within the Torrejonian NALMA (Archibald et al. 1987; Lofgren et al. 2004; Tomida 1980). These faunas occur in a normal polarity zone near the base of an overlying reversed polarity zone (Tomida 1980; Tomida and Butler 1980) and are correlative with many faunas of the Nacimiento Formation from localities exposed in Kutz Canyon, the head of Gallegos Arroyo, De-na-zin Wash, Kimbeto Wash, and Betonnie-Tsosie Wash (Tomida 1980; Williamson 1996; William-

son and Lucas 1993; Lucas et al. 1997). Williamson (1996) placed these localities of the Nacimiento Formation within fossil zones C and D. Fossil zone C localities are all within a normal polarity zone, and zone D localities are all near the base of the overlying reversed polarity zone. These magnetopolarity zones are correlated with subchrons 28n and 27r, respectively. In the Nacimiento Formation, taxa that appear to be restricted to zone C include *Protoselene griphus*, *Paromomys* sp., and a possible mixodectid (not *Mixodectes* but possibly referable to *Dracontolestes*, see Williamson 1996; Williamson and Lucas 1993) represented by an isolated lower premolar. Williamson (1996) defined the *Periptychus carinidens–Protoselene opisthacus* zone (P–P zone) to include this interval. *P. griphus* occurs elsewhere only within the Dragon Canyon local fauna. Its presence in both zone C and the Dragon Canyon local fauna supports a correlation. Fossil zone D is relatively more fossiliferous than zone C and contains fossil localities in Kutz Canyon and the head of Gallegos Canyon. The multituberculate *Catopsalis fissidens* is restricted to zone D in the Nacimiento Formation (Lucas et al. 1997). Williamson (1996) defined the *Protoselene opisthacus–Ellipsodon grangeri* zone (P–E zone) to include this interval. *C. fissidens* certainly occurs elsewhere only within the Dragon Canyon local fauna, and the presence of this taxon within zone D of the Nacimiento Formation supports a correlation with the Dragon Canyon local fauna. Higgins (2003) noted a "questionable" identification of a specimen of *C. fissidens* from the late Torrejonian (To3 sensu Archibald et al. 1987) of the Hanna Formation, Hanna Basin, Wyoming. However, we have not observed this specimen and so are unable to evaluate its identification.

The Farrand Channel of the Tullock Formation of eastern Montana occurs within a reversed polarity interval correlated with subchron 28r (Fig. 7; Swisher et al. 1993; Clemens 2002) and is bracketed by radiometric ages as between 64.52 ± 0.02 Ma and 64.31 ± 0.04 Ma (Wilson 2004; recalculated using the intercalibration of Renne et al. 1998 and Knight et al. 2003) and therefore is older than basal Torrejonian faunas of New Mexico and Utah. It yields a vertebrate fauna, referred to as the Mosquito Gulch local fauna, which is unpublished but may be earliest Torrejonian in age (Lofgren et al. 2004). It contains *Paromomys*, a taxon that elsewhere first appears in the Torrejonian (Lofgren et al. 2004). However, it lacks *Periptychus carinidens* (Clemens, pers. comm. 2007). Biostratigraphic correlation of this fauna with basal Torrejonian faunas, based on the lowest occurrence of *Paromomys*, supports a correlation of the normal polarity zone containing basal Torrejonian deposits of the Nacimiento Formation with subchron 28n.

The Denver Basin contains many early Paleocene vertebrate fossil assemblages

that can also be tied to the GPTS and are constrained by radiometric ages. Most of these are referred to here collectively as the Littleton (including Alexander and South Table Mountain localities) and Corral Bluffs local faunas (Middleton 1983; Eberle 2003; Raynolds and Johnson 2003; Middleton and Dewar 2004). The Alexander and South Table Mountain local faunas both occur within zones of reversed polarity and include mammals indicating an earliest Puercan (Pu1) age. The Corral Bluffs local fauna is in a normal polarity zone and contains taxa indicating a middle Puercan age (Pu2), including *Conacodon entoconus* (Middleton 1983; Eberle 2003). Other taxa are restricted to middle to late Puercan (Pu2–Pu3) including *Ectoconus ditrigonus* and *Periptychus coarctatus* (Lofgren et al. 2004). A volcanic ash from below a vertebrate locality from UCM locality 91278 ("Denver Crockies Locality"; Eberle 2003) that did not preserve age diagnostic mammal fossils yielded a radiometric age of 65.03 ± 0.26 Ma. The ash is stratigraphically approximately 75 m (246 ft) above the Cretaceous–Tertiary boundary based upon projections to the Kiowa core and is in a normal polarity zone correlative with subchron 29n (Eberle 2003; Raynolds and Johnson 2003). Biostratigraphic correlation between Denver Basin vertebrate faunas with Puercan faunas of the San Juan Basin also support correlation of the normal polarity zone containing them with subchron 29n.

Conclusions

Two palynomorph assemblages that were recovered from the Nacimiento Formation are tied to mammal biostratigraphy, biochronology, and magnetostratigraphy. Both palynomorph assemblages, which are reported here, contain palynomorphs that are characteristic of early Paleocene assemblages that are widespread in the Rocky Mountain region. The lower palynomorph assemblage (SJB03-17) contains palynomorphs characteristic of P1–P3 pollen zones. The higher assemblage (SJB03-19) contains palynomorphs characteristic of P3. The SJB03-19 assemblage corresponds to the base of the *Periptychus carinidens–Protoselene opisthacus* fossil zone. This is the first documentation of the direct correlation of the P3 palynozone with a Torrejonian mammal horizon. SJB03-19 occurs in a zone of normal magnetic polarity correlated with subchron 28n. The palynostratigraphic correlation is consistent with this age assessment. The P3 pollen zone spans the two normal polarity subchrons 28n and 27n (Nichols and Fleming 2002); therefore, based on palynostratigraphy alone, a correlation of this normal polarity zone with subchron 27n, as suggested by Fassett (2001, 2007), cannot be falsified. However, such a correlation is at odds with regional mammal biostratigraphy and biochronol-

ogy of the Nacimiento Formation (e.g., Williamson 1996; Lofgren et al. 2004) and of the Naashoibito Member (Williamson et al. 2006). Also, such a correlation would require that a portion of the Naashoibito Member be of Paleocene age (e.g., Fassett 2001, 2007), although the palynostratigraphic evidence used to assert a Paleocene age for the Kirtland Formation has been questioned (Sullivan et al. 2002). We therefore conclude that the normal polarity zone containing SJB03-19 correlates with subchron 28n. Consequently, the vertebrate faunas of the Nacimiento Formation are early Paleocene in age, and the Naashoibito Member of the Kirtland Formation and its vertebrate faunas are Late Cretaceous in age.

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